ual adjustment of the field current matched the voltages. This adjustment resulted in a power factor error when the motor was on the line, and readjustment was necessary.

A commercial power factor control unit was tested to determine its suitability to replace the carbon pile regulator. However, the operation of this unit was not satisfactory because of errors in the order of 5% when the motor was lightly loaded.

b. Description of new unit. A new control was designed, breadboarded, and installed at DSS 13. This control contains line-motor voltage matching circuitry (Fig. 15), and a digital phase detector (Fig. 16) for power-factor control after the motor is brought on the line.

The line-motor voltage matching section of the motor field control contains a voltage transducer, which is a full-wave bridge that is linearized by the use of a small value of resistance in parallel with the output resistance. A transducer is used on both the line and motor voltages. The dc voltage output of these transducers is then applied to a voltage comparator circuit whose output controls the motor field-power supply.

The power factor section of the motor field control consists of a digital phase detector, which samples the motor current and motor-voltage phase relationship. The output of the phase detector is zero at unity power factor,

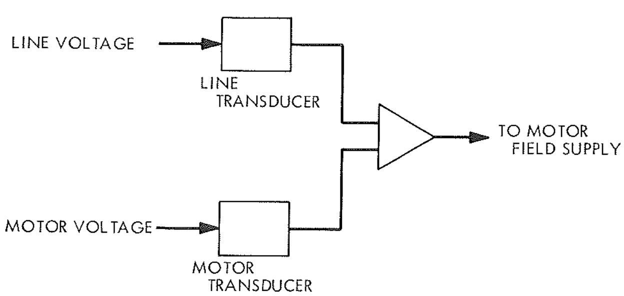

Fig. 15. Line-motor voltage matching circuit

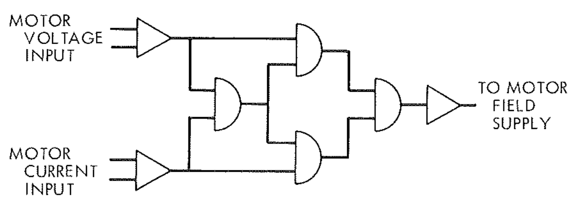

Fig. 16. Digital phase detector logic

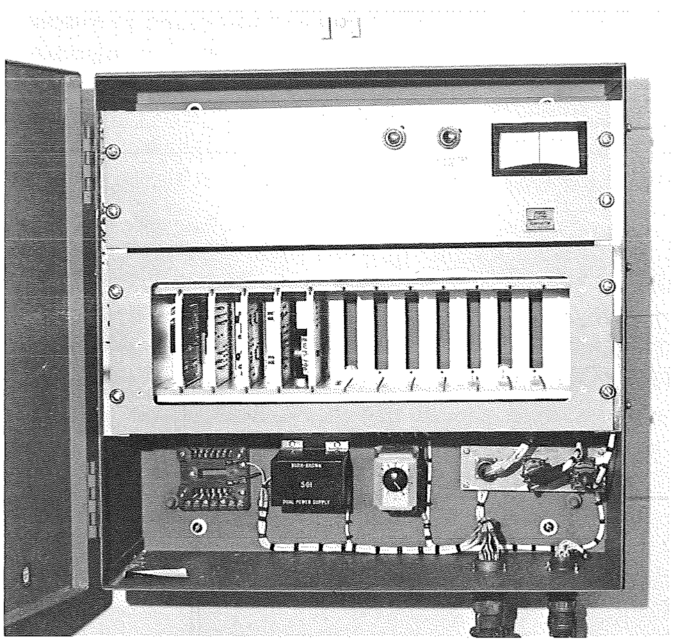

Fig. 17. Prototype motor field control on time-synchronization transmitter

positive for a leading power factor, and negative for a lagging power factor. This output is integrated and applied to an operational amplifier capable of driving the motor field-power supply, resulting in a power-factor control that is not dependent upon line variations nor upon motor loading for control. Laboratory tests of the phase detector showed an accuracy of ±0.5% at worst-case conditions.

The original breadboard has been in operation at DSS 13 in the S-band system for approximately 1 yr with no failures. A prototype (Fig. 17) has been built and installed in the X-band clock synchronization transmitter system of DSS 13. Operation of this unit has been satisfactory for about three months.

c. Future plans. Two production units are scheduled to be delivered during the next reporting period. One of these units will replace the original breadboard model at DSS 13, and the other will be installed at DSS 14 during December of this year.

B. DSN Projects and Systems Development

1. Clock-Synchronization System Performance, *H. W. Baugh*

a. Introduction. A precision clock-synchronization network is being established to meet the requirements of the DSN. The immediate goal for this system was to provide synchronization between all DSSs committed to *Mariner* Mars 1969 to within 20 μs at the time of planetary encounter. A second objective is to provide correlation to the National Bureau of Standards (NBS) or to the U.S. Naval Observatory (USNO) to within 5 μs for the DSN as a whole.

The system uses a computer-controlled transmitter at DSS 13 to send timing signals to the remote DSSs by way of an X-band carrier that is reflected from the surface of the moon. References to previous articles are given in SPS 37-56, Vol. II, pp. 142–143. The most recent article on the system was in SPS 37-57, Vol. II, pp. 151–152. The present article will cover the operations of the system from April 15 to October 10, 1969.

b. Implementation. The installation of clock synchronization equipment at four overseas DSSs was completed during this period. DSS 41 went into operation on June 20. DSS 42 made a gradual transition from the prototype receiver to the new equipment, replacing one assembly at a time. (Its first complete operation using all new equipment took place on June 25.) DSS 62 became operational on July 5, followed by DSS 51 on July 22.

The signal-to-noise performance of the new receivers at DSS 41 and 42 was initially very poor; the cause was determined to be the leakage of 100-kHz pulses into the 100-kHz IF amplifier via the +12 Vdc supply line to the oven of the crystal filter. All the new units were rewired to make use of other supply voltages that did not have the 100 kHz noise. Following this change, all the receivers performed satisfactorily and the system could be used to adjust the DSS clocks into close synchronization for the *Mariner* Mars 1969 encounter operations.

c. Calibration. The clock at DSS 14 can be checked by two different measurement techniques. The clock-synchronization receiver provides one means; timing signals direct from the Goldstone Standards Laboratory (via microwave link) provide the other. Since the latter signals are also sent to DSS 13, the offset of DSS 14 with respect to DSS 13 is known to within 1–2 μs. The error of closure between the known offset at DSS 14 and the clock-synchronization receiver measurement gives the sum of the calibration errors of the clock-synchronization system. These errors arise from delays in the equipment, from ephemeris errors, and from large variations in lunar topography. Since earlier results at DSS 42 had been sufficiently stable, it was assumed that calibration data of this sort would not be absolutely necessary. However, a reconfiguring of the sources of reference frequencies at DSS 13, made about July 15, led to an instability in the transmitter coder that caused the calibration of the system to show jumps of as much as 10 μs from one day to the next.

Consequently, on July 27, the DSS 14 clock-synchronization receiver was activated and DSS personnel were trained in operations and data reduction so as to monitor the system during the *Mariner* Mars 1969 encounter periods.

d. Performance. Figures 18 and 19 show the clock offsets with respect to NBS clock CL-8 during a 10-day period around the two encounter events. The clock-synchronization measurements at the overseas DSSs have been corrected for the closure errors observed at DSS 14. These data are shown in comparison with the time polynomials used in the Orbit Determination Program, which are derived by collating all other forms of timing data, i.e., very-low frequency tracking, simultaneous ranging, and some LORAN-C data. It will be seen that the results are all within the ± 20 μs goal, except at DSS 51 where there appears to be an offset of about 30 μs. Further analysis will be required to resolve this problem, which may be due to errors in assessing the data that led to the time polynomials.

e. Current work. A new transmitter coder has been installed at DSS 13. Initial tests indicate that it is not subject to the instability that disturbed the older unit. Further testing is in process.

The prototype receiver has been returned from DSS 42. After it is refurbished, it will be sent to the USNO. When installation is complete, an extensive evaluation will be made over a period of 1 or 2 mo to assist in determining the nature of the ephemeris-related errors in the system.

2. Multiple-Mission Telemetry System Project,

W. S. Baumgartner, N. C. Ham, W. F. McAndrew, D. W. Brown, M. L. Yeater, C. A. Holritz, J. T. Hatch, and A. D'Amore

a. Introduction. The Multiple-Mission Telemetry System (MMTS) Project was established in February 1967 to design, test, and install throughout the DSN a telemetry system capable of supporting all foreseeable spacecraft, and with performance close to the theoretical. To provide support for *Mariner* Mars 1969, the equipment was required by mid-1968. These objectives have all now been met. All DSN stations, as well as the Compatibility Test Station at Cape Kennedy and the Compatibility

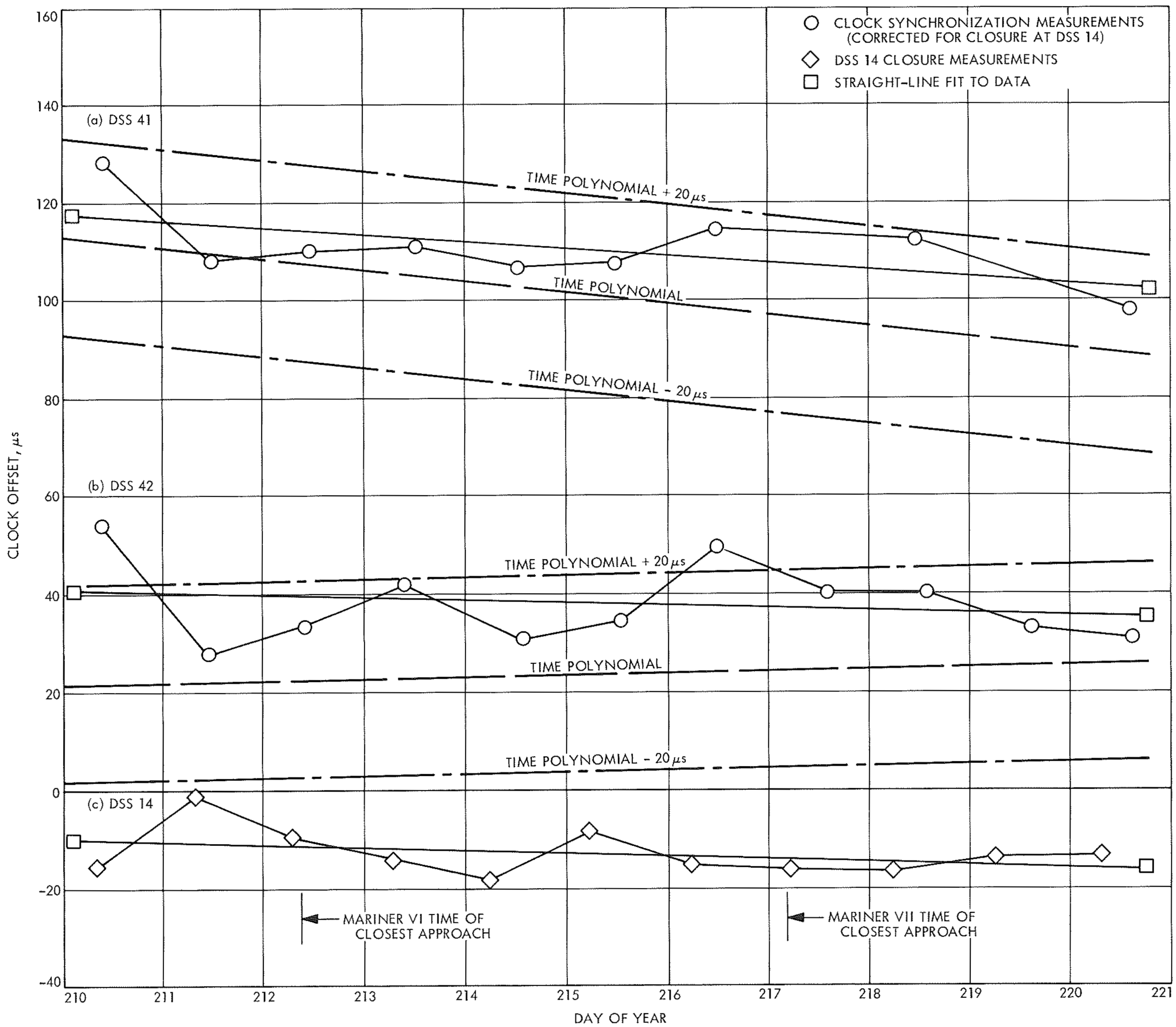

Fig. 18. Clock-synchronization performance for DSSs 41, 42, and 14

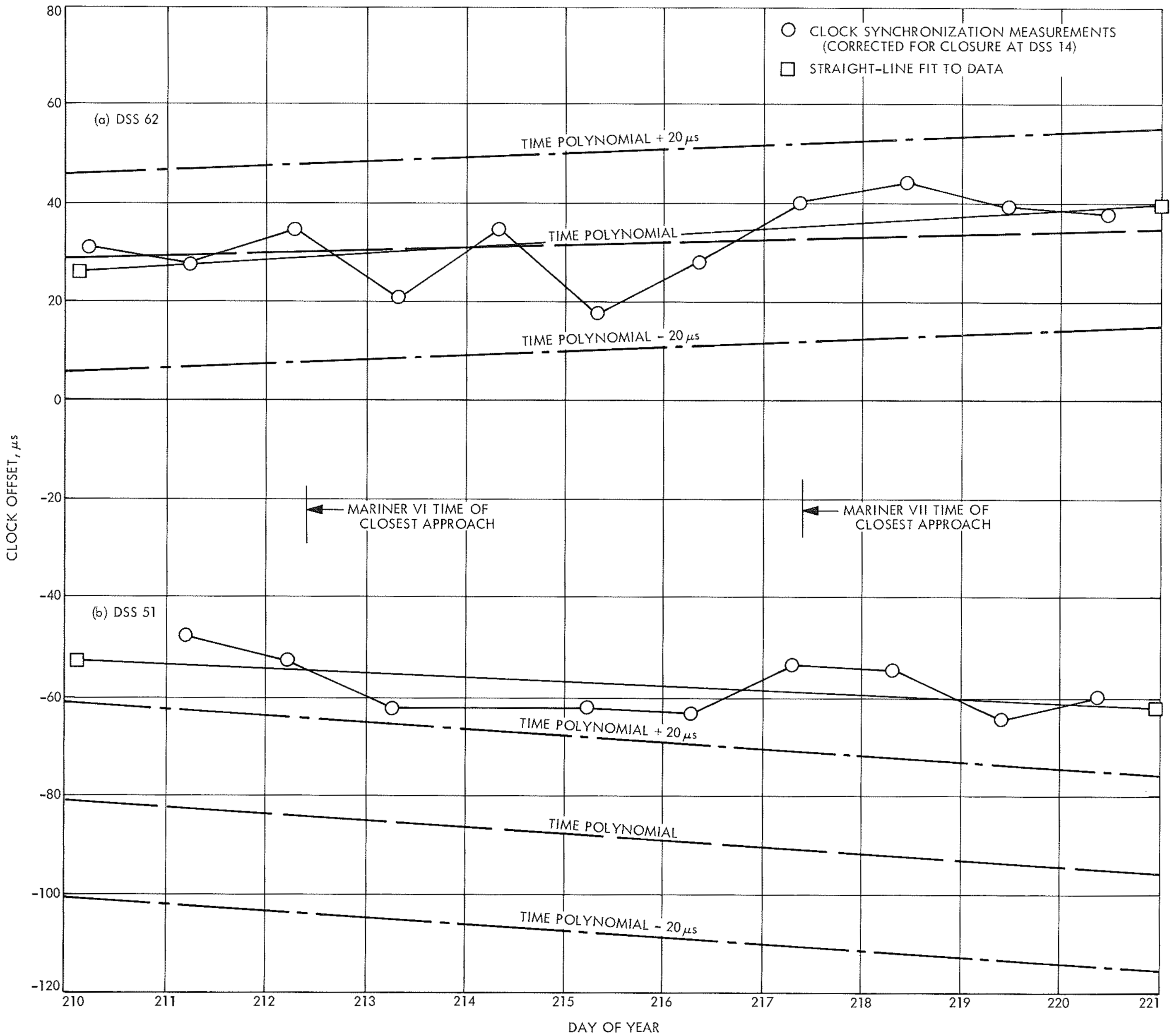

Fig. 19. Clock-synchronization performance for DSSs 62 and 51

Test Area (CTA) at JPL, are equipped with MMTS; the equipment has been extensively evaluated in the laboratory and has successfully supported the *Mariner* and *Pioneer* Projects with performance improved over previous systems.

Detailed analysis and interim test results have been presented in SPS 37-52, Vol. II, pp. 119–143, SPS 37-50, Vol. II, pp. 3–14 and 52-54, SPS 37-49, Vol. II, pp. 98–113, SPS 37-47, Vol. II, pp. 138–142, and SPS 37-46, Vol. III, pp. 175–243. In this article, which will be the final report from the project, an attempt will be made to present the final test results and compare these with the original specifications, outline the present status of the hardware, discuss changes to support future requirements, and report on operational use and results.

b. System verification test.

Performance classification. The objective of this test is to verify the performance of the DSIF MMTS function for non-coded digital pulse-code modulated (PCM) data. Performance is measured by determining the demodulated data probability of error P_e as a function of the overall system's input sideband signal energy per bit-to-noise spectral density ratio ST_B/N_0. Figure 20 is a block diagram of the method used for obtaining measurement data. The input ST_B/N_0 is adjusted for specific values and the detected data is then compared against the input reference data to determine the resultant bit error rate (BER).

To establish a means for evaluating the system's performance characteristics, the system is divided into (1) the receiver assembly, (2) the subcarrier demodulator assembly (SDA), and (3) the telemetry processor assembly. Specific efficiency coefficients of the assemblies can then define the system's performance characteristics (Fig. 21). The definition of the effective input sideband signal-to-noise for a given bit rate can be stated as

$$R_0 = \frac{ST_B}{N_0}(p)\,(q)\,(r) = \left(\frac{ST_B}{N_0}\right)\text{eff} \tag{1}$$

In addition to Eq. (1), an additional coefficient m, due to measurement error, is included to normalize the expected test measurements. Therefore,

$$R = R_0(m)$$

$$R = \frac{ST_B}{N_0}(p)\,(q)\,(r)\,(m) = \left(\frac{ST_B}{N_0}\right)\text{eff} \tag{2}$$

where

R = effective ST_B/N_0

p = efficiency coefficient due to RF receiver tracking loop error

q = efficiency coefficient due to subcarrier reference jitter error

r = efficiency coefficient due to bit synchronization timing jitter error

m = measurement error

(1) ***RF receiver loop efficiency coefficient p.*** The equation derived by W. C. Lindsey (Ref. 1) determines the theoretical receiver efficiency coefficient as a function of (ST_B/N_0) eff or R evaluated for various receiver car-

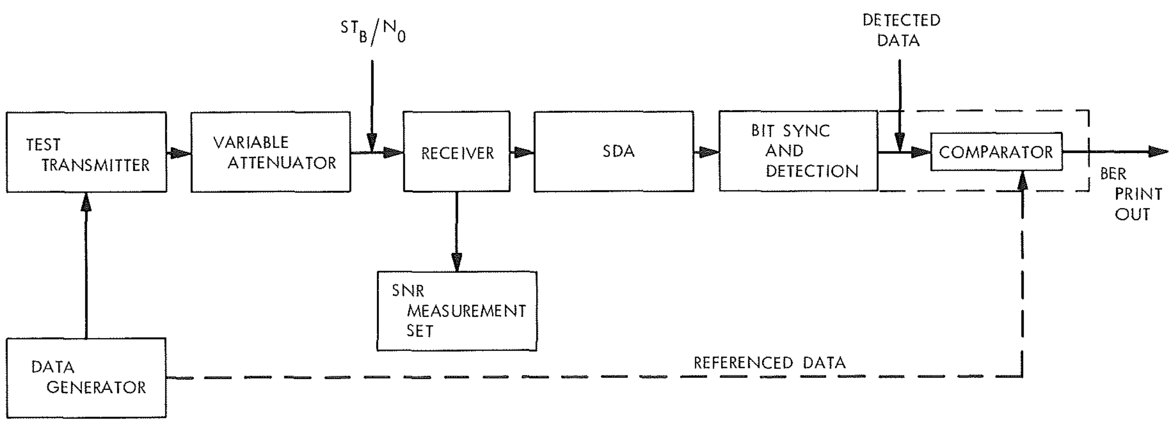

Fig. 20. System performance measurement method

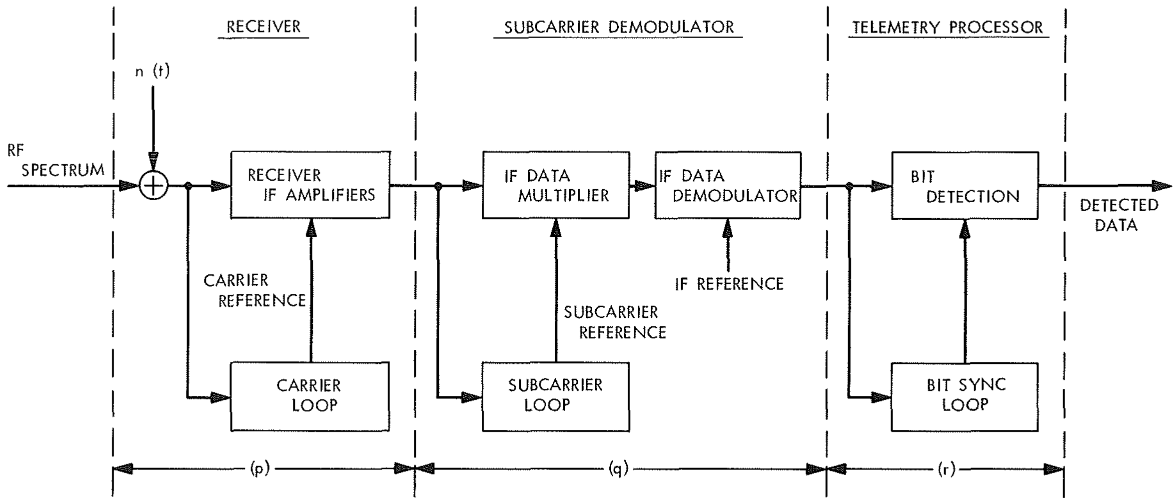

Fig. 21. Simplified system diagram

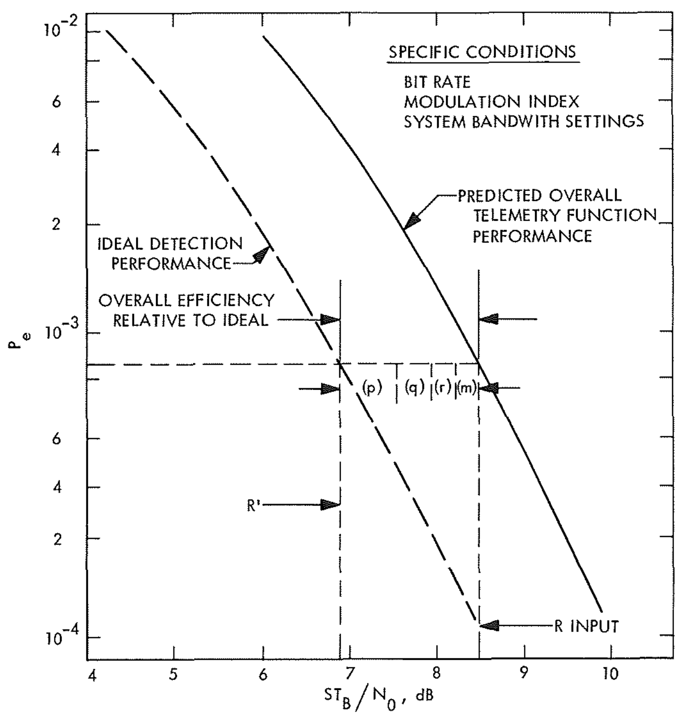

Fig. 22. Graphical relationship of general efficiency equation

rier loop bandwidth signal-to-noise ratios (SNRs). This equation is expressed as

$$P_E = \int^{\pi} \frac{\exp(\rho/\gamma \cos\phi)}{\pi I_0(\rho/\gamma)} \operatorname{Erfc}\left[(2R)^{1/2}\cos\phi\right] d\phi \qquad (3)$$

(2) ***Subcarrier demodulation efficiency coefficient q.*** The ratio of the effective output ST_B/N_0 to the input ST_B/N_0 of the SDA determines the efficiency coefficient for this assembly. An analysis by M. H. Brockman (SPS 37-46, Vol. III), derives this coefficient as a function of the phase error and is represented by

$$(q) = \frac{\text{output } ST_B/N_0}{\text{input } ST_B/N_0} = \left[1 - \left(\frac{2}{\pi}\right)^{3/2} \sigma_{\theta_n}\right]^2 \qquad (4)$$

where σ_{θ_n} is the rms phase noise error.

(3) ***Bit synchronization timing efficiency coefficient r.*** The efficiency coefficient due to bit synchronization is more conveniently expressed by the loss in the SNR due to timing jitter of the data correlator. J. W. Layland (SPS 37-46, Vol. III) has derived an expression for determining this loss as follows:

Effective SNR =

$$\frac{ST_B}{N_0}\left\{1 - 2\left(\frac{K}{(1-K)}\left[\frac{1}{8}\left(\frac{N_0}{ST_B}\right)^2 + \frac{5}{32}\left(\frac{N_0}{ST_B}\right)\right]\right)\right\}^{1/2}$$

(4) ***Overall system efficiency.*** By combining all the efficiency coefficients, and expressing in units of dB, the overall system efficiency becomes:

$$R(\text{dB}) = S(\text{dB}) + T_B(\text{dB}) + p(\text{dB}) + q(\text{dB}) + r(\text{dB}) + m(\text{dB}) - N_0(\text{dB})$$

Figure 22 is the graphical representation of the overall system efficiency equation relative to the ideal detection performance.

Test method. Figure 23 is a block diagram of the system test arrangement used for the verification tests. The telemetry test set provides the reference data for comparison against the detected data and the data-modulated subcarrier for the input test signal. The modulated subcarrier then phase modulates a test transmitter that provides the S-band input signal to the overall telemetry system. The input signal is adjusted to specific values of ST_B/N_0 whose value can be measured by the SNR measurement equipment. After data detection, and comparison to the reference data, the resultant BER is determined.

(1) ***Method of establishing input ST_B/N_0.*** The technique used for establishing the input ST_B/N_0 consists of accurately measuring the ratio of carrier plus noise power-to-noise power (Y-factor) with the SNR measurement equipment. The power indicator M_1, which measures the power within the 50 MHz bandpass frequency, is adjusted for a reference value with the RF signal source off. Then, the desired ratio $(P_c + P_n)/P_n$ value is inserted in the precision attenuator A_3. With the RF power on and no modulation, attenuator A_2 is adjusted until the power level at indicator M_1 is returned approximately to the reference value. Finally, the true resultant $(P_c + P_n)/P_n$ is accurately measured with A_3. As an example of the adjustment and measurement necessary for a specific test, a typical calculation will be shown. Desired condition:

$$ST_B/N_0 = 5.2 \text{ dB. } (1/T_B = 270 \text{ bits/s})$$

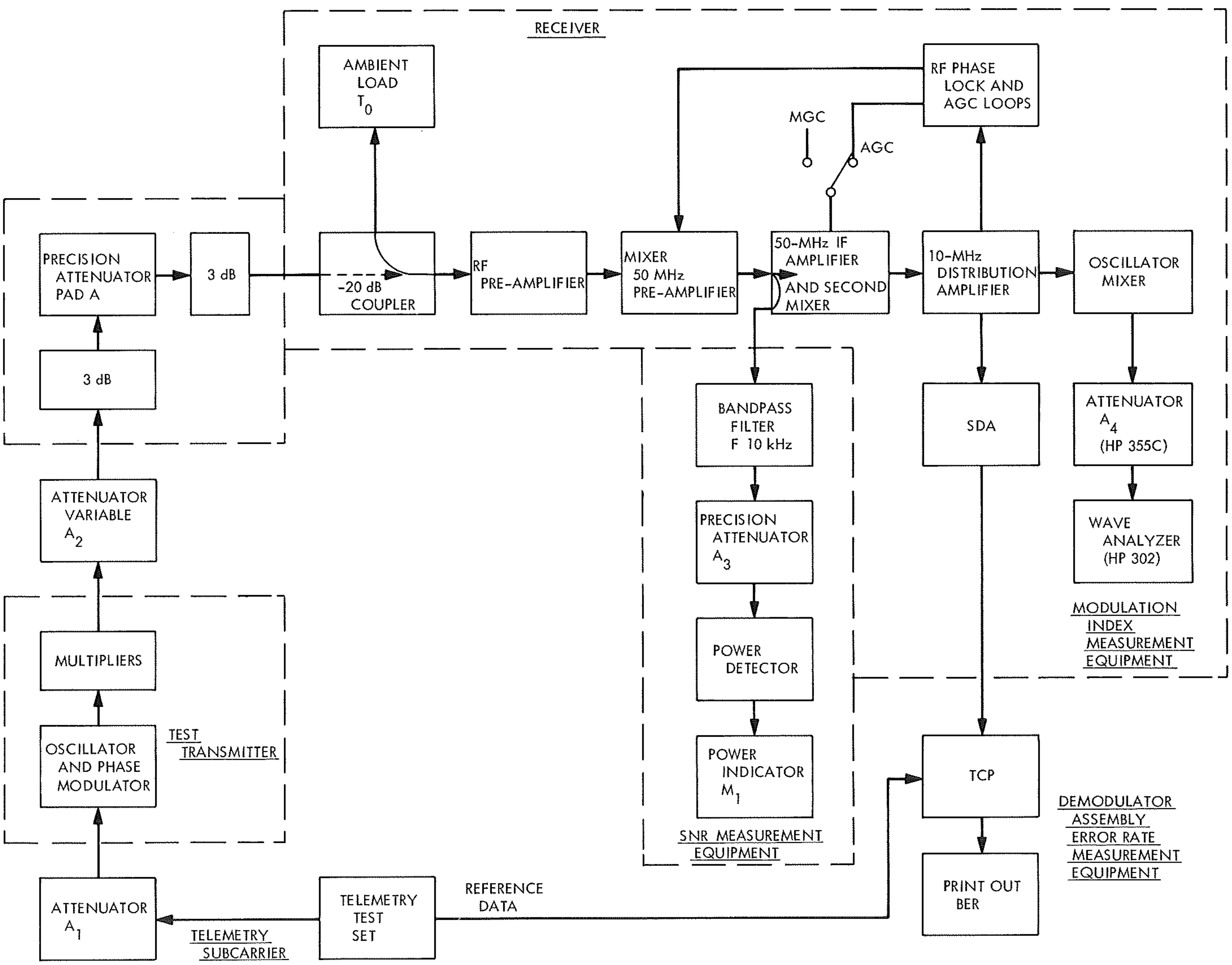

Fig. 23. System verification test arrangement

Then

$$ST_B/N_{0_{\text{ratio}}} = 3.311/\text{bit rate duration}$$

$$S/N_{0_{\text{ratio}}} = 893.97 \text{ for specific bit rate}$$

$$S/N_{0_{\text{dB}}} = 29.51 \text{ dB}$$

$(F$, filter bandwidth$)$ = 9.867 kHz (typical noise bandwidth value)

Relative bandwidth correction = 39.94 dB Hz, (10 log 9.867 kHz)

Hence, $S/N_{\text{dB}} = -10.43$ dB required in 9.867 kHz bandwidth (29.51 dB − 39.94 dB). The desired quantity, S/N, is actually the data SNR or $S/N = P_{\text{data}}/P_n$; however, the measured quantity is the carrier SNR without modulation or P_{total}/P_n.

Assuming squarewave modulation and a modulation index of 66.5 deg,

$$\frac{P_{\text{carrier}}}{P_{\text{total}_{\text{dB}}}} = -8.0 \text{ dB}; \left[\frac{P_c}{P_t} = +20 \log \cos 66.5 \text{ deg carrier suppression}\right]$$

where

$$P_{\text{total}} = P_{\text{carrier}} + P_{\text{data}} \text{ or } 1$$

$$= \frac{P_c}{P_t} + \frac{P_d}{P_t} = \cos^2\theta + \sin^2\theta$$

$$\frac{P_{\text{data}}}{P_{\text{total}_{\text{dB}}}} = -0.75 \text{ dB}; \left[\frac{P_d}{P_t} = +20 \log \sin 66.5 \text{ deg}\right]$$

$$\frac{P_{\text{data}}/P_n}{P_{\text{data}}/P_{\text{total}}} = \frac{P_{\text{total}}}{P_n}; \frac{P_{\text{total}}}{P_{n_{\text{dB}}}} = -9.68 \text{ dB}$$

This value would be most difficult to set up and measure directly. Hence, the P_{total} value is set and measured instead at some value above the required value of −9.68 dB. This is accomplished by setting P_{total}/P_n to a modified value with the precision attenuator pad A by-passed (Fig. 24a); then, by replacing the precision calibrated attenuator in the signal line, the proper value P_t/P_n ratio will exist.

Example

Assume that a 20-dB calibrated attenuator is utilized then

$$\frac{P_{\text{total}}}{P_n} = -9.68 \text{ dB} + 20.0 = +10.32 \text{ dB}$$

or

$$\frac{P_{\text{total}}}{P_{n_{\text{ratio}}}} = 10.77$$

and

$$\frac{P_{\text{total}} + P_n}{P_{n_{\text{ratio}}}} = 10.77 + 1 = 11.77$$

Thus,

$$Y_{\text{dB}} = \frac{P_{\text{total}} + P_n}{P_{n_{\text{dB}}}} = 10.71 \text{ dB}$$

which now becomes the setting of the modified Y-factor value.

(2) ***Evaluation of measurement errors.*** The measurement error associated with the determination of the input ST_B/N_0 value is comprised of instrumentation accuracies, human factor error in reading the reference marks, and equipment stability during the time of the measurement and test. A tabulation of the contributing errors is as follows:

Error	Value, dB
Y-factor = attenuator accuracy meter	±0.05
resetability	±0.05
A = precision attenuator pad	±0.05
F = noise bandwidth accuracy	±0.05
MI = attenuator accuracy	±0.10
= meter resetability	±0.05
= system linearity error	±0.05
$P_T(t)$ = time stability of output power for duration of each data point	±0.05
Worst case error total	±0.45

Test results. Verification system test results are shown in Fig. 24a–e. These results are for specific system operational control settings within the DSSs such as receiver loop bandwidth, subcarrier loop bandwidth, and bit synchronization loop bandwidth. The output BER as a function of the input ST_B/N_0 for a specific bit rate and modulation index becomes the variable parameter. The theoretical ideal phase-shift-keyed (PSK) detection characteristic is shown for reference purposes together with the predicted curves that were obtained by combining the theoretical efficiencies of the various elements of the telemetry system. Measured values should then be displaced from the predicted curve no greater than the

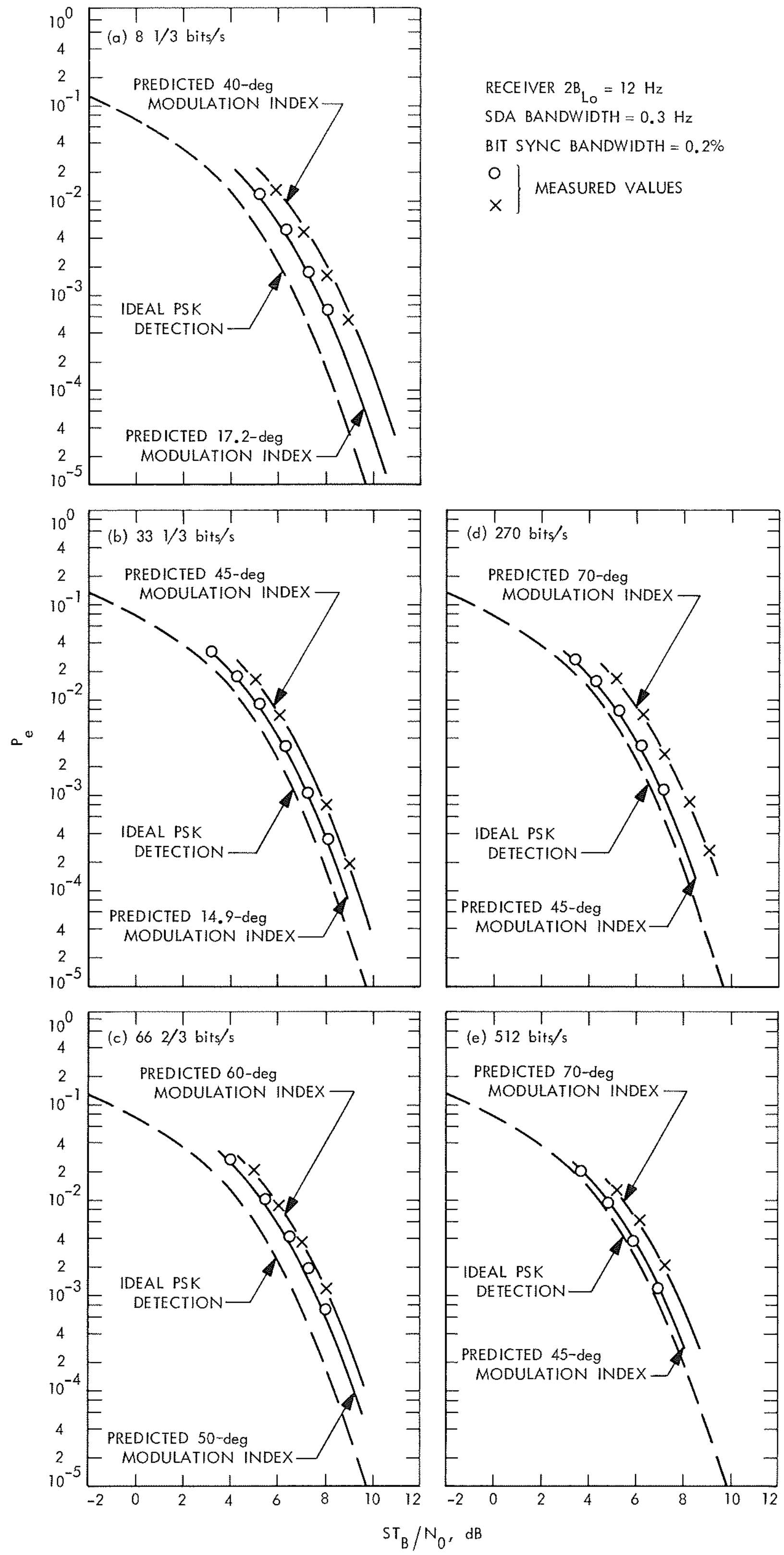

Fig. 24. System verification test results

measurement error if the theoretical analyses for the efficiencies were correct. The results shown on the curves indicate the performance of the MMTS as being very close to theoretical.

*c. **Receiver modifications.*** The addition of the SDAs to the receiver–exciter subsystem requires that portions of the receiver–exciter be modified to create an interface to this new equipment.

Prior to the installation of the SDAs, four receiver output signals at 10 MHz were required (Fig. 25). Two of these outputs were assigned to telemetry, one was an undetected output at low level for recording, and the other was a phase detected output providing a baseband signal at high level for recording and further processing. This baseband signal was then processed in the telemetry and command data handling subsystem.

The present method of operation requires SDAs to receive the modulated 10-MHz IF carrier from the receiver. The SDAs then process these signals and extract the data from the telemetry subcarriers. Each SDA requires the following signals from the receiver:

Function	Level
10 MHz reference	+10 dBmW
10 MHz IF (receiver 1)	−55 dBmW
10 MHz IF (receiver 2)	−55 dBmW
5 MHz reference	+10 dBmW
Switching	28 Vdc
Lamp	24 Vdc

Since the number of SDAs that will be interfaced with the receiver–exciter varies from one to six, the modification kits were designed to handle six SDAs at all sites.

In addition to the 10-MHz modulated signal from the receiver, each SDA requires 10- and 5-MHz reference signals. These were provided in the receiver–exciter interface. Four unused 10-MHz reference signals in cabinet 8 of the receiver–exciter were made available at the cabinet 8 interface plate. The 5-MHz reference signal was utilized only by the receiver–exciter synthesizer and no distribution of this signal was previously made. In order to furnish this reference to the SDAs, a 5-MHz distribution amplifier, similar in construction to the 10-MHz IF signal distribution amplifier, was installed in a previously unused module location of the receiver–exciter (cabinet 4). The 5-MHz signal from the frequency and timing subsystem (FTS) is distributed to the receiver–exciter synthesizer and to the SDAs from this subassembly (Fig. 26).

The +28-Vdc switching supply voltage and the +24-Vdc lamp supply voltage were made available on multipin connectors at an interface plate located at the rear of receiver–exciter cabinet 7.

The receiver–exciter subsystem required three new subassembly types to provide the proper signals and levels to the SDAs. When first designed, the SDA interface modification kit had a requirement for 10-MHz modulated IF signals at a level of −66 dBmW. An IF signal distribution amplifier was designed and installed to provide these outputs. This −66 dBmW requirement was subsequently changed to −55-dBmW to provide the capability of handling modulation indices from 11 to 72-deg peak. It was then necessary to design and supply an additional 10-MHz distribution amplifier to increase the interface signal to this new level. The modifications to the receiver consist of the addition of the following three new subassemblies:

10-MHz IF signal distribution amplifier. This subassembly replaces the old 10-MHz IF signal distribution amplifier. It provides eight output terminals at a level of −66 dBmW, three of which are spares. The subassembly is physically located in cabinets 5 and 8, location A402 (the same location as the replaced subassembly).

10-MHz distribution amplifier. This subassembly is required to increase the signal level by 11 dB to −55 dBmW and provide six output terminals for the SDAs. Physically, this subassembly is mounted in a location that formerly held a larger size subassembly. It was therefore necessary to provide an adapter plate for mounting (cabinets 5 and 8).

5-MHz reference distribution amplifier. This subassembly is required to distribute the 5-MHz reference signal from the FTS to the receiver–exciter synthesizer and the SDAs. It is physically located in cabinet 4, location A102, which previously held a blank plate.

The SDA uses a 24-MHz voltage-controlled oscillator (VCO) in the subcarrier tracking loop. In order to accurately set the VCO frequency and eliminate the need to search in order to lock the subcarrier loop, the VCO frequency is held at 24 MHz ±6 Hz maximum.

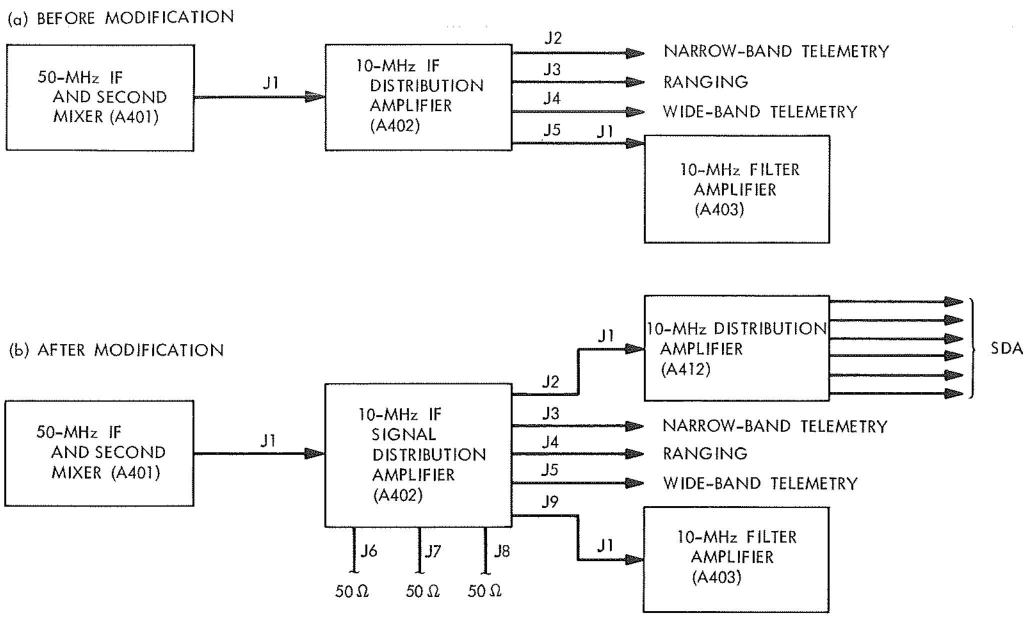

Fig. 25. SDA—receiver–exciter functional interface (cabinets 5 and 8)

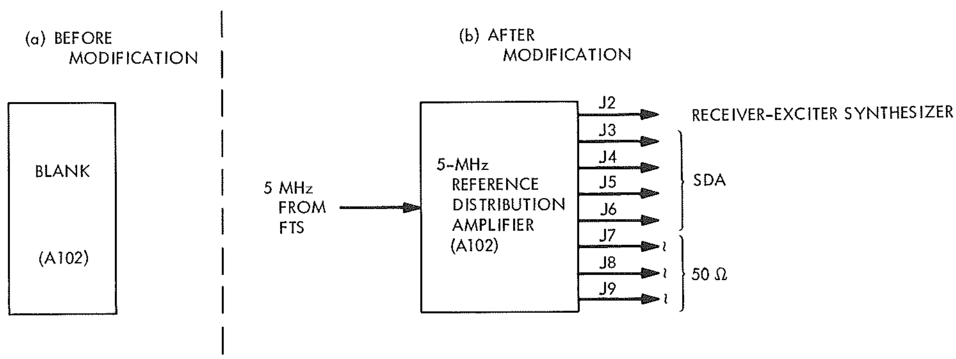

Fig. 26. SDA—receiver–exciter functional interface (cabinet 4)

The receiver–exciter was modified so that the SDA VCO frequency can be monitored on a frequency counter in the receiver control cabinet and adjusted to the proper frequency.

d. SDA. The SDA has had virtually no design changes since the article appeared in SPS 37-49, Vol. II. However, there were two changes made to accommodate the received signal as it became better defined. Each consisted of a temporary measure to be followed by a permanent modification.

Modification 1. The range of modulation indices to be received is in excess of the original 0–12 dB modulation index control provided. The temporary solution has been to increase the signal level at the receiver interface and to insert a switchable 10-dB attenuator in series with the 0–12 dB control in the SDA. To improve operability and assure future flexibility, the 0–12 dB attenuator is being replaced with a 0–24 dB attenuator.

Modification 2. The nature of the data streams typically used is not compatible with the high pass filtering at the SDA output. This was originally provided to avoid hardware-generated dc offsets at the input to the telemetry and command processor (TCP). During the *Mariner* Mars 1969 period, this filter was bypassed and the offset zeroed out on a daily basis at the data isolation amplifiers at the SDA output. For future applications, the entire high pass filter assembly will be deleted and new design 10-MHz wideband amplitude detectors will be provided with significantly improved dc stability.

Additionally, there have been several design improvements at the subassembly level to improve producibility and reliability.

Since the period covered by the article in SPS 37-52, Vol. II, 20 SDAs have been implemented at nine DSSs and the JPL CTA. These are now operational. Ten additional SDAs are currently under contracted manufacture to implement the tenth DSS as well as added capability at four of the existing sites.

Beginning in the *Mariner* Mars 1971 time period, the MMTS configuration will change significantly. Perhaps the most significant change will be the implementation of symbol synchronizer assemblies (SSA) and associated decoders. Presently, a redesign of the output interface of the SDA is being performed to accommodate the SSA and to improve SDA performance at data symbol rates as high as 270,000 symbols/s. The latter will be accomplished essentially by means of improved frequency response of the data channel and by reduction of incidental time delay in the generation of the "data estimate" as used in the SDA demodulation process.

e. Telemetry and command data subsystem. Figure 27 shows a functional block diagram of a DSS with the MMTS. That part of the MMTS capability residing in the telemetry and command data (TCD) subsystem is the symbol synchronization–detection software described in SPS 37-46, Vol. III. This provided the TCD subsystem with the capability for processing a single telemetry data stream for each TCP (SDS 920) computer.

Future missions require that each TCP computer have a dual MMTS data stream capability. In addition, there is a requirement for higher and more variable data rates, and for handling of biorthogonal comma-free encoded data streams (SPS 37-48, Vol. II, pp. 83–130). Therefore, the expanded MMTS capability to the TCP subsystem will include an SSA, a block decoder assembly, added digital recorders, a 4800-bits/s high-speed data line (HSDL), and a mission-independent software assembly. A project has been established for the implementation of these added capabilities. A functional block diagram of a DSS with the expanded MMTS capability is shown in Fig. 28.

f. Mariner Mars 1969 operational experience.

Mariner Mars 1969 pre-mission preparation. A major milestone of the DSN in preparing for the *Mariner* Mars 1969 Mission was the achievement of DSS operational readiness in November 1968. The information contained herein concerning the MMTS operator training and operational testing programs conducted by the DSIF will provide an insight into the level of effort that was required to implement this new system for *Mariner* Mars 1969 flight support.

(1) ***DSIF operator training.*** The philosophy for training DSIF operators to support the *Mariner* Mars 1969 Mission was developed by the DSIF Operations Section in August 1967. This philosophy was reflected in the general plan that was incorporated into the *Mariner* Mars 1969 Mission Operations Training Plan. The detailed program and procedures were published in Volume VII of the DSN Test Plan for *Mariner* Mars 1969 Project. While the training program covered all aspects of *Mariner* Mars 1969 operational support by the DSIF, it was heavily MMTS-oriented because of the uniqueness of the new equipment and software.

Prior to commencement of the first phase of the training, a considerable amount of preparation had to be completed. During July and August 1968, the instructors were trained and their course material was prepared. This was accomplished by having the instructors participate in MMTS equipment installation and testing activities at the JPL CTA, during which time they also compiled their course material.

Briefly, the DSIF operator training for MMTS encompassed formal training at the Goldstone DSCC, operational exercises at the JPL CTA, and on-site classroom instruction and training exercises. The training courses at the Goldstone DSCC and the JPL CTA were attended by an operations supervisor and two senior MMTS operators from each *Mariner* Mars 1969 DSS (DSSs 12, 14, 41, 51, 62, and 71). The DSIF Operations Team also participated to the extent that the *Mariner* Mars 1969 Lead Controller attended the Goldstone DSCC course and the entire Net Control Team in the SFOF supported the exercises with the JPL CTA. A brief description of each of the three major phases of the MMTS training is given in the following three paragraphs.

The 2-wk operator training course at Goldstone DSCC was conducted from September 3 through 13, 1968, under the auspices of the DSIF Training Unit. The formal classroom instruction and laboratory exercises covered were the TCP, including the MMTS and related software, and the SDA portion of the MMTS. The objective was to train the operators in operation of the equipment for the *Mariner* Mars 1969 Mission, performance of trouble-

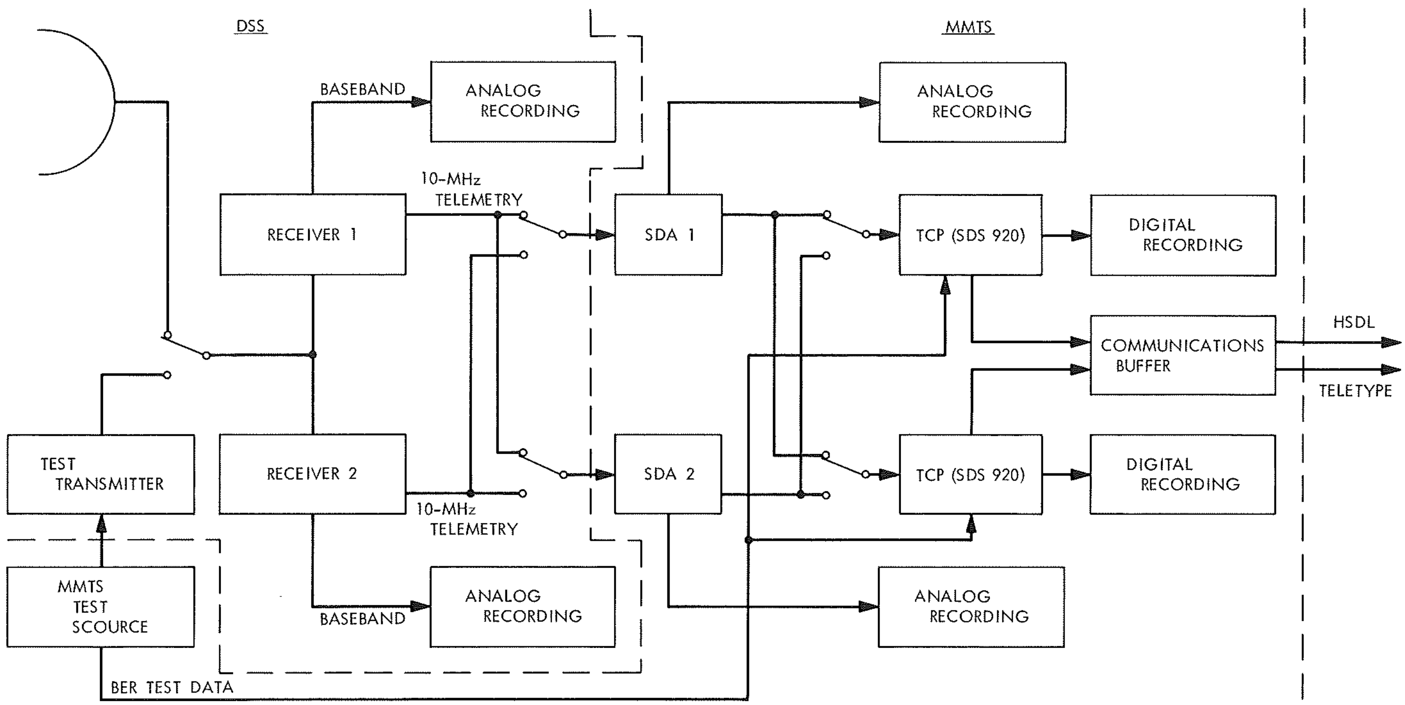

Fig. 27. DSIF MMTS functional block diagram

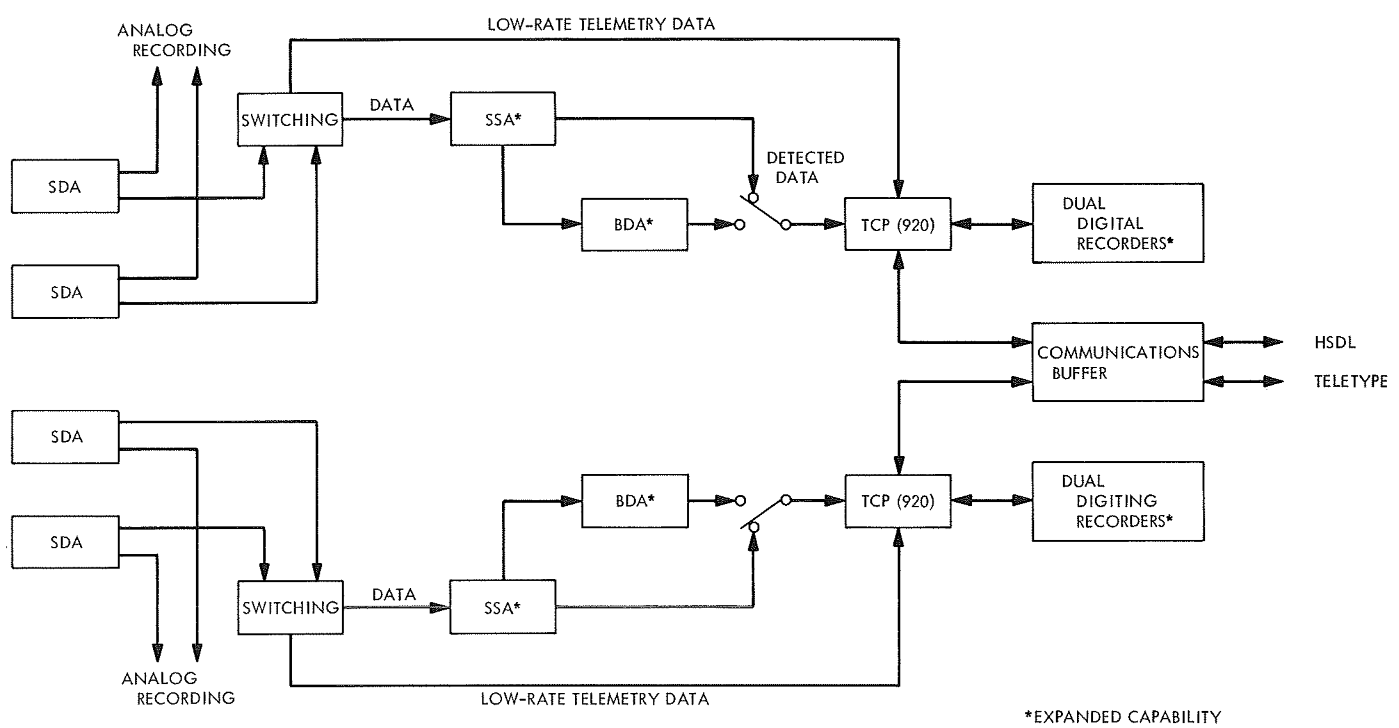

Fig. 28. TCD subsystem expanded MMTS capability

shooting and preventive maintenance on the equipment, and use and operation of software (computer programs) for the mission, including thorough familiarization with software–equipment interfaces.

Operator training at the JPL CTA, which was accomplished from September 16 through 27, 1968, provided the operators with an opportunity to apply what they had learned during the Goldstone DSCC courses. Under supervision and control of its operations supervisor, each DSS team participated in training exercises in which they operated CTA equipment, utilizing DSIF operating procedures and software for *Mariner* Mars 1969. These exercises included counting down and calibrating the CTA equipment, and then using a live *Mariner* Mars 1969 spacecraft in the Spacecraft Assembly Facility as a data source to perform a simulated track. The DSIF Operations Team also benefitted from this training in the SFOF (DSIF Net Control), which afforded them their first opportunity to participate in realistic *Mariner* Mars 1969 operations and become familiar with the telemetry data formats and operational aspects of the MMTS.

Operator on-site training commenced about October 1, 1968 on return of the above mentioned trainees to their respective DSSs. It consisted of formal classroom instruction (similar to that given at the Goldstone DSCC) and "in house" operational tests designed to exercise the DSS in its *Mariner* Mars 1969 configuration. The program was based on the provision that the limited number of operators trained at the Goldstone DSCC and the JPL CTA would train other operators at their respective DSSs utilizing a training package (course material on the MMTS) supplied by the DSIF Training Unit at the Goldstone DSCC. A continuing and comprehensive program was conducted at each DSS to assure that sufficient qualified MMTS operators were available to support all pre-launch and mission activities.

(2) ***DSIF operational testing.*** Pre-launch *Mariner* Mars 1969 testing activities involving MMTS operations that were supported by the DSIF included DSIF integration tests, DSIF operational verification tests (OVTs), DSN system tests, DSIF configuration verification tests (CVT), Mission Operations System (MOS) training tests, operational demonstration tests (ODTs), and operational readiness tests (ORTs). Combined with the DSS in-house testing and training exercises, the DSIF, DSN, and MOS testing put a considerable amount of operational running time on the MMTS. The successful and trouble-free use of MMTS to support actual flight operations can be attributed largely to the thorough shake-down and valuable experience gained during the pre-launch test exercises. This test participation is summarized in Table 4; the amount of MMTS pre-launch operating time is estimated at approximately 300 h/DSS. From the standpoint of DSIF ability to operate the MMTS, the DSIF integration tests and OVTs were the most significant of the tests shown in Table 4. The brief descriptions of integration tests and OVTs given in the following paragraphs will help explain why this is so.

DSIF integration tests, which were critical to the checkout and implementation of the operational MMTS software, were the first used to exercise each DSS in its *Mariner* Mars 1969 configuration. The configuration of each DSS was defined and controlled by Volume VI of the DSN Operations Plan for *Mariner* Mars 1969 Project.

The tests were performed in three phases in accordance with Volume VI of the DSN Test Plan for *Mariner* Mars 1969 Project. The first test, an interface verification test,

Table 4. DSS pre-launch *Mariner* Mars 1969 test participation summary

Test	Number of tests supported						
	DSS 71[a]	DSS 12	CTA[a]	DSS 41	DSS 51	DDS 62	Total
DSIF integration test[b]	1	1	1	1	1	1	6
DSIF OVT	1	11	7	8	8	8	43
DSIF CVT	1	1	1	1	1	1	6
DSN system test	2	2	—	2	2	2	10
MOS system training test	1	1	10[c]	1	1	1	15
MOS ODT[d]	3	3	—	4	3	3	16
MOS ORT	2	2	—	2	2	2	10
Total	11	21	17	19	18	18	106

[a]Not shown are the numerous spacecraft–MOS–DSIF compatibility tests in which these stations participated.

[b]This consisted of a series of tests for a total of 40 h of MMTS operation at each station.

[c]These were Spacecraft Performance Analysis and Command—Technical Analysis Group training exercises using a *Mariner* Mars 1969 spacecraft in the SAF as a data source.

[d]Final test ran for four consecutive 24-h days.

provided final certification that all interfaces with the TCP system operated properly. Next, BER checks were performed to verify proper operation of RF–MMTS–TCP interfaces and provide determination of MMTS performance when operating at or near design threshold levels. Finally, a data flow test (from DSS to SFOF) was run to verify the proper integration of the *Mariner* Mars 1969 TCP program into the DSS and the *Mariner* Mars 1969 software system.

Following completion of the integration tests at each DSS, OVTs were run in accordance with Volume VII of the DSN Test Plan for *Mariner* Mars 1969 Project. These tests exercised not only the DSIF, but also the other elements (GCF and SFOF) of the DSN. They were specifically designed to verify compatibility of the *Mariner* Mars 1969 operating procedures (DSN Operations Plan, Volume VII), equipment, and operational interfaces. They also demonstrated the adequacy of the training of all DSIF operational personnel at the DSSs and in the SFOF.

Successful completion of an OVT was the last step in the process of meeting DSS operational readiness dates. OVTs were run with the DSSs subsequent to their respective readiness dates as required to maintain proficiency and verify the operational capability of newly-trained operators.

Mariner Mars 1969 flight support. As would be expected from the success of the DSIF and DSN pre-launch testing and ability of the MMTS to support the numerous MOS tests, the MMTS performed extremely well during the flight phases of the mission. The few system limitations that were encountered were easily circumvented, either by the use of special operating procedures or by software changes. Some of the more relevant aspects of MMTS performance during flight support operations, including the encounter phase of the mission, are discussed below.

(1) ***Telemetry data retrieval.*** To date, well over 99% of the telemetry data available during scheduled DSS tracking periods has been retrieved in flight operations. For example, from launch through the midcourse maneuver (February 25 to March 15, 1969) of *Mariner VI*, 99.83% of the telemetry data were retrieved. During the corresponding period for *Mariner VII* (March 27 to April 15, 1969), telemetry data retrieval increased to 99.99%. The negligible amount of data lost by the DSIF throughout the mission is attributed largely to DSS ground receiver out-of-lock conditions, which occurred as a result of standard tracking procedures associated with turning the ground transmitters on or off.

With two SDAs, two TCPs and recorders, and an FR 1400 recording of the SDA outputs being provided by the standard *Mariner* Mars 1969 DSS configuration, irretrievable loss of data by a DSS was virtually impossible if either of the two ground receivers was in lock. In those cases where communications circuit (HSDL and teletype) outages precluded real-time transmission of data to the SFOF, the MMTS recording capabilities made it possible for a DSS to play a TCP log tape directly back to the SFOF, play an FR 1400 analog tape into the TCP and thence to the SFOF, and mail the TCP log tape to JPL Document Control in the SFOF. All of these methods of retrieving telemetry data were used successfully during the mission.

(2) ***Operational performance.*** In assessing the overall operational effectiveness of the MMTS, two factors are particularly noteworthy. One is that no emergency changes to the software had to be made for *Mariner* Mars 1969 after completion of the DSIF integration tests. This can be attributed to the thoroughness of the testing and adequacy of TCP program changes made during software development and DSS implementation phases. The other factor is that the original operational program, *Mariner* Mars 1969 TCP Computer Program, was re-written only once after launch. This re-write was accomplished in a very orderly and evolutionary fashion. The new version was thoroughly tested and accepted by the DSIF prior to commencement of the MOS pre-encounter operational tests. Although designed primarily to benefit the *Mariner* Mars 1969 software system, the changes facilitated DSIF–MMTS operations as well.

TCP log tape validation was a problem during the early weeks of the mission. It was found that the information provided by the *Mariner* Mars 1969 TCP computer program regarding quality of the log tape recordings could be misleading. The program printed out the number of "write errors" and records lost on each tape (a "record" consisting of a block of telemetry data). However, it was found that, in many instances, the "write errors" actually were tape recorder "read errors," and that the data actually were properly recorded (no actual "write errors" or "records lost"). The problem still exists with the current version of the software; however, a new TCP computer program (On-site *Mariner* Mars 1969 Log Tape Validation Program) was developed by the DSIF Operations Section to resolve the matter. This program makes it possible to determine immediately after a DSS tracking period the percentage of good telemetry data that were recorded on each TCP log tape.

The downlink SNR data provided by MMTS proved to be an extremely valuable operational tool during the mission. It is the best indicator of overall telemetry system performance yet seen by the DSIF. As examples, it provided an immediate indication of DSS receiver lock on a sideband and/or wrong spacecraft telemetry bit rate selected for the TCP, and signaled substandard MMTS performance or impending equipment failure so that corrective action could be taken before a telemetry data outage occurred.

(3) ***Encounter operations.*** MMTS performance during *Mariner* Mars 1969 encounter and playback operations was particularly gratifying. Of special significance were the methods employed by the DSIF Operations Section to operate the Goldstone DSCC/JPL CTA configuration and to overcome a design incompatibility between the MMTS and *Mariner* Mars 1969 spacecraft that affected operations during this period.

The high-rate telemetry (HRT) experiment was an unqualified success from the standpoint of DSIF operations. Six HRT playbacks per spacecraft were accomplished and the data recorded on TCP log tapes by DSS 14. Further, virtually all the data from the first HRT playback of each spacecraft were received and processed in the SFOF in real time. The success of the HRT playbacks (at 16.2 kbits/s) makes it unlikely that the *Mariner* Mars 1969 Project will go to the expense and effort of processing the low-rate (270 bits/s) science log tape recordings made in the SFOF and at the 85-ft-diam antenna DSSs.

The configuration used to support the Goldstone DSCC passes of both the encountering and non-encountering spacecraft was a very complex operational structure. Volume VI of the DSN Operations Plan for *Mariner* Mars 1969 Project details this configuration. Briefly, it involves DSSs 11, 12, and 14 at the Goldstone DSCC and the JPL CTA. The operational employment of MMTS in this configuration is given in Table 5.

During Mode 1 operations (Table 5), DSS 11 was assigned to track the non-encountering spacecraft while, at the same time, DSSs 12 and 14 were tracking the encountering spacecraft. Since DSS 11 was not equipped with a TCP, the SDA 2 output (spacecraft engineering data) was microwaved to the JPL CTA, where the data were processed in TCP B and then transmitted to the SFOF via HSDL and teletype. For the encountering spacecraft, HRT data were processed in both TCPs (A and B) at DSS 14, normally utilizing the output from SDA 1 (not shown in Table 5). To provide HRT data in real time to the SFOF, the SDA 4 output was microwaved to the JPL CTA where it was processed in TCP A and then transmitted to the SFOF for processing in a Univac 1219 computer and display on television. The output of SDA 2 at DSS 14 was microwaved to DSS 12 where it was processed in TCP B. DSS 12 transmitted either the DSS 14 or its own engineering telemetry data to the SFOF, with the DSS 14 data being "prime."

Not shown by Table 5 is the fact that certain spacecraft telemetry channels were teletyped from the JPL CTA back to DSS 11 and from DSS 12 to DSS 14 in real time. This was required for proper completion of the DSS command readiness procedures.

The foregoing simplified explanation of the MMTS utilization in support of *Mariner* Mars 1969 encounter operations should serve to illustrate the unique and operational situation that faced the DSIF. That the whole operation was 100% successful is a tribute not only to the capabilities of the MMTS, but also to the professional competence of the DSIF operators, both at the DSSs and in the SFOF.

(4) ***Special procedures for telemetry mode changes.*** The design characteristics of the *Mariner* Mars 1969 spacecraft flight telemetry (TM)–RF subsystems and the DSIF ground receiver (RCV)/SDA subsystems resulted in an inherent incompatibility that affected the ENCOUNTER 2 and PLAYBACK 1 and 2 spacecraft TM modes. This was because of the fact that in these science modes, the exceptionally low spacecraft engineering subcarrier modulation index (11.9-deg minimum as opposed to about 41 deg when science was not present) exceeded the limits of the RCV–SDA ground equipment if the equipment settings established during pre-cals remained unaltered.

Since the problem was caused in part by the characteristics of the spacecraft engineering subcarrier, the capability to process engineering TM was affected at the 85-ft-diam antenna DSSs, as well as at DSS 14, which was the only *Mariner* Mars 1969 DSS capable of processing the 16.2-kbits/s HRT data. Therefore, an operational procedure utilizing a non-standard configuration was initiated to circumvent the problem. This procedure facilitated the altering of the relationship between the RCV attenuator and SDA modulation index settings,

Table 5. MMTS data flow during Goldstone DSCC encounter passes

DSIF mode (No. and purpose)	DSS equipment	Non-encountering spacecraft coverage			Encountering spacecraft coverage		
		DSS 12	DSS 11	CTA	CTA	DSS 14	DSS 12
1 HRT Standard	TCP A TCP B SDA 2 SDA 4		ENG	X	X	HRT HRT ENG HRT	ENG X X
2 HRT DSS 11 not scheduled	TCP A TCP B SDA 3 SDA 2	ENG X ENG X			X X	HRT HRT HRT ENG	
3 Science DSS 11 not scheduled	TCP A TCP B SDA 2	SCI X ENG X			X	SCI X ENG X ENG	
4 Science standard	TCP A TCP B SDA 2		ENG	X		SCI X ENG X ENG	SCI X X
5 HRT DSS 12 antenna failure	TCP A TCP B SDA 2 SDA 4		ENG	X	X	HRT HRT ENG HRT	X X
6 Science DSS 14 antenna failure	TCP A TCP B SDA 2		ENG	X			SCI X ENG X
7 HRT DSS 11 antenna failure	TCP A TCP B SDA 2 SDA 4				X	HRT HRT ENG HRT	ENG X X

NOTE: X Indicates on-site processing and standard transmission to SFOF.
→ Indicates microwave link.
ENG $33\frac{1}{3}$ bits/s engineering data.
SCI $66\frac{2}{3}$ or 270 bits/s science data.
HRT 16,200 bits/s science data.

which were prescribed by Volume VI of the DSN Operations Plan. The detailed operational procedure was published as a change to Volume VII of the DSN Operations Plan.

There were three operational difficulties associated with this design problem. Any change to these modulation settings immediately invalidated the DSS RCV automatic gain control (AGC) prepass calibrations unless additional AGC calibrations were carried out for each anticipated setting prior to a pass. Any change to the SDA setting automatically caused loss of SDA–TCP lock, resulting in loss of TM data from any single DSS. That is, if the settings were changed prior to the spacecraft mode changes, TM data were lost until after the new mode was observed (to ensure receipt of the last available bit of the outgoing TM, a portion of the incoming new mode was forfeited). This problem was obviated by using two DSSs in parallel, whenever possible, with one changing settings before, and one after, the spacecraft TM mode changes. The main operational problem was that the control knobs for these settings, particularly on the RCV, were never intended for real-time operational changes and are physically located such that the RCV operator has to leave his position at the RCV console to carry out the changes at a critical time, when it is imperative that he be able to observe and correct any loss of RCV lock.

The effects of the aforementioned problems on MMTS operations were minimized by the design and issuance of the detailed operational procedure. During the pre-encounter testing, both the DSS operators and DSS controllers in the SFOF practiced the coordination and developed the proficiency necessary to effect the adjustments without incurring a loss of spacecraft TM data.

g. Pioneer Project operational experience. The *Pioneer* MMTS program was initially produced on a crash basis as a model to demonstrate the real-time telemetry processing capability of the DSN facility at JPL. A minimum amount of manpower effort was expended to design the program. Therefore, the current *Pioneer* Telemetry Processing Program is limited in certain areas and could be improved if the program were redesigned to be used for full operational flight support in place of the current mission-dependent equipment.

The use of the MMTS for support of the *Pioneer* Missions has been limited to the cruise phases of the mission. All data processed have been at the 8-bits/s rate. All MMTS passes for *Pioneer* have been one-way tracking without command capability. The prime support has been provided by DSS 41. Project benefits derived from the MMTS operations have been limited to science data in real-time and analog tapes for backup. The digital recordings could not be processed by the Ames Research Center under the current MMTS configuration.

Systems description. The *Pioneer* Telemetry Processing Program is used to frame sync, decommutate, and display the *Pioneer* telemetry data to the user in real time. The data are received into the IBM 7044 computer from the DSIF. The DSIF site uses a modified *Mariner* Mars 1969 TCP program in an SDS 920 computer to bit-sync and package the telemetry data for transmission to the SFOF. The data are transmitted to the SFOF over Automatic Data Switching System (ADSS) lines. After signal conditioning the ADSS data in synchronizing units, the data are passed to the IBM 7044 computer where they are received by the mission-independent system. The data are then passed to the *Pioneer* Telemetry Processing Program where the actual processing of the data takes place. After the data have been identified, they are passed back to the IBM 7044 mission-independent system for printer formatting and output to the user area.

Software description. The *Pioneer* telemetry data are transmitted from the DSIF site to the SFOF in 600-bit ADSS blocks of data. Each block contains 168 bits of raw telemetry data plus other related data such as spacecraft number, DSIF number, data type, and other related data. The raw telemetry data are transmitted to the SFOF in the order they are received from the *Pioneer* spacecraft. This means that the program in the IBM 7044 computer must synchronize the frames of data from the completely unsynchronized input data blocks. Since a frame of data is 224 bits in length, a frame cannot be held by one ADSS data block alone but requires a portion of another data block. A frame of data could utilize three data blocks for transmission if the beginning of a frame started near the end of an ADSS block. The frame would require the whole (168 bits) of the next block plus a small portion of the following block.

When the ADSS data blocks are received by the IBM 7044 mission-independent system, three header words are attached to the beginning of each block and one trailer is attached to the end of the block. The data blocks are placed into an internal IBM 7044 buffer called ADEBnn, where nn is the spacecraft number of the spacecraft that is sending the data. These buffers are passed to the *Pioneer* Telemetry Processing Program for processing.

The only other inputs to the *Pioneer* Telemetry Processing Program are in the form of punched cards. These cards are used to specify the sync pattern that should be used to synchronize the data into frames, and as a constant to specify to the program the number of telemetry frames to bypass between sending a frame of data to the teleprinters. The "sleeving" of data to the teleprinters is necessary so that the teleprinters do not fall behind in their printing of data frames. Other data inputs to the IBM 7044 computer are directed to the mission-independent system from the message composer units. These messages include process requests, printer and teleprinter output requests, and others.

Program limitation. The current MMTS program for *Pioneer* does not allow for two-way tracking nor will it handle *Pioneer* data rates above 256 bits/s. No consideration was made for interfacing with convolutional coding operations for *Pioneer IX*. Spacecraft AGC and static phase error at the DSS for data rates above 64 bits/s is lost.

The existing program does not output engineering formats required for *Pioneer* operations. Additional limitations in the IBM 7044 area are:

(1) Limited to 4 HSDLs input to the SFOF at one time.

(2) One IBM 7044 will not handle two HSDLs from the same spacecraft (will not process data from both stations during periods of overlap).

(3) Will not output to HSDL.

(4) Writes separate telemetry original data record by project, not by spacecraft.

Pioneer Mission requirements. Future *Pioneer F* and *G* Missions will be dependent both on the redesigned MMTS program, and the upcoming Multiple-Mission Command System Program. Mission-dependent equipment currently used on *Pioneers VI, VII, VIII,* and *IX* will be phased out for the Multiple-Mission Telemetry and Command Systems to be employed at JPL.

Reference

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